is treated as a matrix. The general term for this process is "crosstalk correction", since it removes the information from a source that has fallen into a channel adjacent of the correct channel. This information spillover is analogous to crosstalk in bundled telephone lines, which results in a listener hearing the conversation from another line.

This set of equations must be solved for each pixel location. It is essential, then, that the images from all of the channels be precisely aligned with one another so that the correct measurements are entered into the equations for each pixel location. Therefore, a computational process is applied to the images belonging to a field of view before the crosstalk correction is applied. The "field of view" is the scene captured in an image. The images belonging to a field of view may be referred to as the "image ensemble" for that field of view.

FIGURE 24 is a block diagram of the operations required to carry out the spatial and spectral corrections. It includes two significant image processing operations, applying spatial corrections executed in a block 305 and applying spectral cross talk corrections, executed in a block 306. In block 305, the images from a plurality of channels are spatially aligning, and in block 306, corrections are applied to remove the channel-to-channel crosstalk. There are two classes of information that support the operations executed in blocks 305 and 306. The first is the class of calibration constants, derived from on-line calibration of the instrument during its operation. The second class of supporting information is that for which stored tables of constants are accessed during operation, but not modified.

In a block 301, a calibration image that is generated from a plurality of offset stripes (the spatial offset for the calibration image being known) is introduced to the instrument. The instrument then computes the spatial offsets between the stripes in a block 302. The X,Y (horizontal and vertical) spatial offsets are determined in a block 303. Note that the image misalignment responsible for such spatial offsets may be subject to thermal drift and other factors that may vary during operation. The X,Y spatial offsets are used in block 305, along with other information, to apply spatial corrections.

The stored constants will have been derived from measurements and from the known characteristics of the objects to be imaged. Different stored constraints will be applied to the spatial corrections executed in block 305 than are applied to the crosstalk corrections executed in block 306. For example, the general positions of the channels relative to each other known, and these positions are required for the spatial corrections executed in block 305. The stored data relating to the general positions of the channels relative to each other are provided to a processor executing the spatial corrections of block 305 in a block 308. With respect to the crosstalk corrections executed in

block 306, stored data relating to the inverted source coefficients are provided in a block 309. It should be noted that additional stored measurements and known characteristics can also be incorporated into the second class, and provided to the spatial correction operation or the crosstalk correction operation, as appropriate.

The image processing stages can be applied in real-time as images are collected during system operation, or by offline access to stored image files. The images to be spatially and spectrally corrected in blocks 305 and 306 are provided by a block 304. The resulting corrected images are output in a block 307, and are suitable for further processing and analysis, free of the information degradation caused by crosstalk and misalignment.

A block diagram of the general operations of the preferred embodiment of the present invention is shown in FIGURE 25. An "Image Ensemble" refers to a set of images, all of which depict the same field of view, but each of which has been constructed of signals from a particular channel. The number of images in an ensemble is equal to the number of channels in the instrument. The image ensemble is generated in a block 401.

The X (horizontal) and Y (vertical) offsets are required in order for the alignment process to operate on the image ensembles. These offsets are provided in a block 403. As discussed above with respect to FIGURE 24, calibration images are processed to determine these offset values. The calibration process may be run as a preliminary step in the operation of the instrument. The calibration may be repeated periodically to track drift in the image registration caused, for example, by changes in temperature. The process of generating the offsets is illustrated by a block diagram in FIGURE 26.

In a block 404, images are aligned by shifting rows by pixel increments. In a block 406, an aligned image is generated by a floating point interpolation in a, using interpolation kernels generated in a block 405, based on the X,Y offsets determined in block 403. In a block 407, the crosstalk correction process described above is applied, using a spectral coefficient matrix provided by a block 408. Then in a block 409 the 8-bit grayscale is restored, resulting in a final image ready to output in a block 402.

Referring now to the block diagram of FIGURE 26, for each image, represent by a block 501, a first operation in the generation of the spatial offsets is that of boundary detection, executed in blocks 502 and 503. From the boundary information determined in block 502, a Fourier Transform is applied in a block 504, and then a Fast Fourier Transform is applied in the reference channel. From the boundary information determined in block 503, a Fourier Transform is applied in a block 505, and then a Fast Fourier Transform is applied in the data channel. The results of both Fast Fourier

Transforms are multiplies in a block 508, and an Inverse Fourier Transform is applied to the result in a block 509. Then accumulated 2D correlograms (1 per data channel) are generated in a block 510. The process is repeated for additional images. A detailed description of the process illustrated in the block diagram of FIGURE 26 is provided below. Note that FIGURE 27 illustrates exemplary images before and after correction.

A two-dimensional gradient operator is used to suppress flat surfaces and to enhance object boundaries. The operator builds signal in regions where the slope of the intensity is large in both the vertical and the horizontal directions. The linear expression for this operator is as follows:

$$G = \frac{\partial}{\partial y}\frac{\partial I}{\partial x}.$$

Object boundaries carry all of the energy in the images transformed by the gradient operator. What is needed next is a way to overlay each data image onto the reference image and measure how much vertical shift and horizontal shift is required to line up the object boundaries. Cross-correlation is a preferred method for measuring these shifts, or offsets, between images.

The cross-correlation of two signals is comprised of convolving the two signals and extracting information from the output of the convolution operation, which is called the correlogram. The operation of convolution in the time domain is defined by the following equation:

$$f_1(t) \otimes f_2(t) = \int_{-\infty}^{\infty} f_1(\lambda) f_2(t-\lambda)\, d\lambda.$$

The value of the convolution for every time sample, t, is the sum over infinity of the product of the two functions, but with the second function offset by time t. The time delay between the two signals can be determined by finding the peak in the correlogram.

For image realignment, the convolution is applied in two dimensions to functions in x,y space, as follows:

$$f_1(x,y) \otimes f_2(x,y) = \iint_{-\infty}^{\infty} f_1(\varepsilon,\eta) f_2(x-\varepsilon, y-\eta)\, d\varepsilon\, d\eta.$$

The alignment method is based on the premise that there will be similar structures in the images to be aligned. In the ideal case, the second image is identical to the first except for a shift in x and y. Furthermore, the shift can be represented as the convolution of the function with the two-dimensional Dirac delta function, thus:

$$f_2(x,y) = f_1(x-x_0, y-y_0),$$

and

$$f_2(x,y) = f_1(x,y) \otimes \delta(x-x_0, y-y_0).$$